Light Dark Matter searches with positrons at JLab

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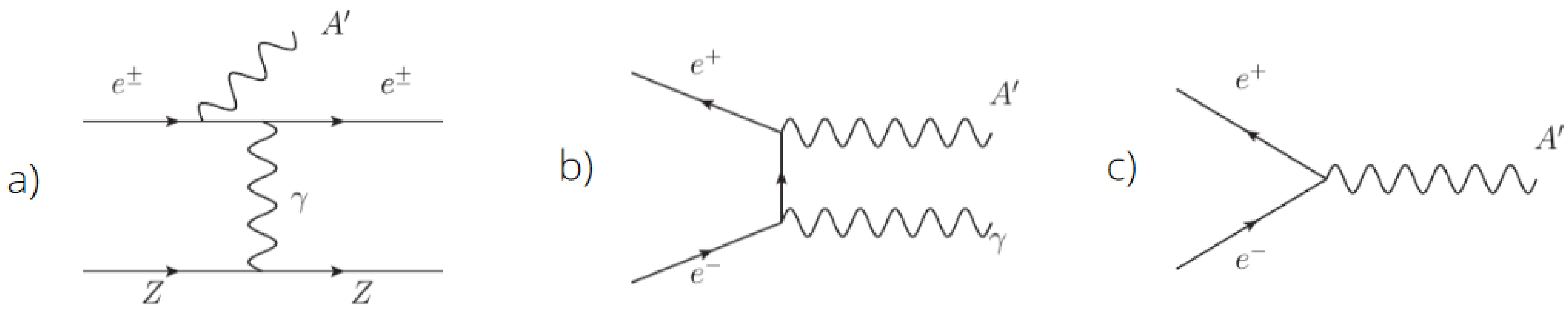
Dark Photon production with an e^+ beam

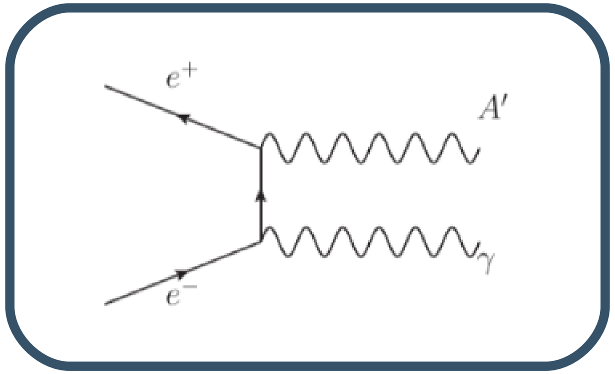
Dark photon (A’) can be produced in electron-positron collision through three main process:

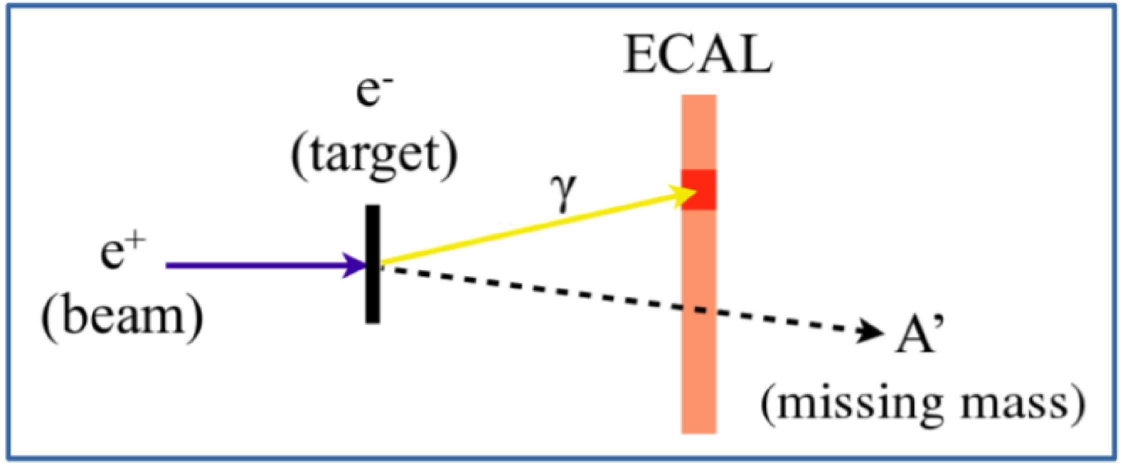


- a) A’-strahlung: used in fixed-target e^- beam experiments. **α^3** scaling
- b) Non-resonant annihilation: **α^2** scaling
- c) Resonant annihilation: **α** scaling

Both resonant and non-resonant annihilation can be used to search for A’ in ***thick*** and ***thin target*** experiments.

Thin target experiment (PADME)





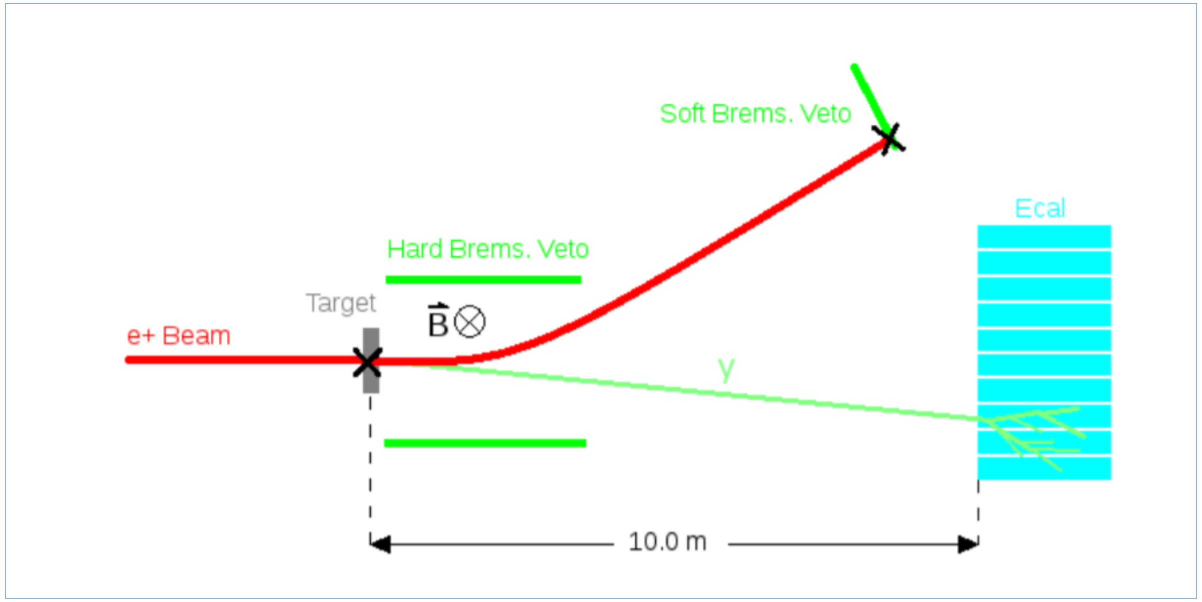
- Probing *A'* with e+ on thin target (e.g. PADME at LNF, *High Energy Phys.* 2014:959802; VEPP-3, arXiv:1207.5089 [hep-ex])
- Produced *A'* leaves the detector volume without interacting
- Detect recoiling photon with EM calorimeter and compute the Missing Mass:

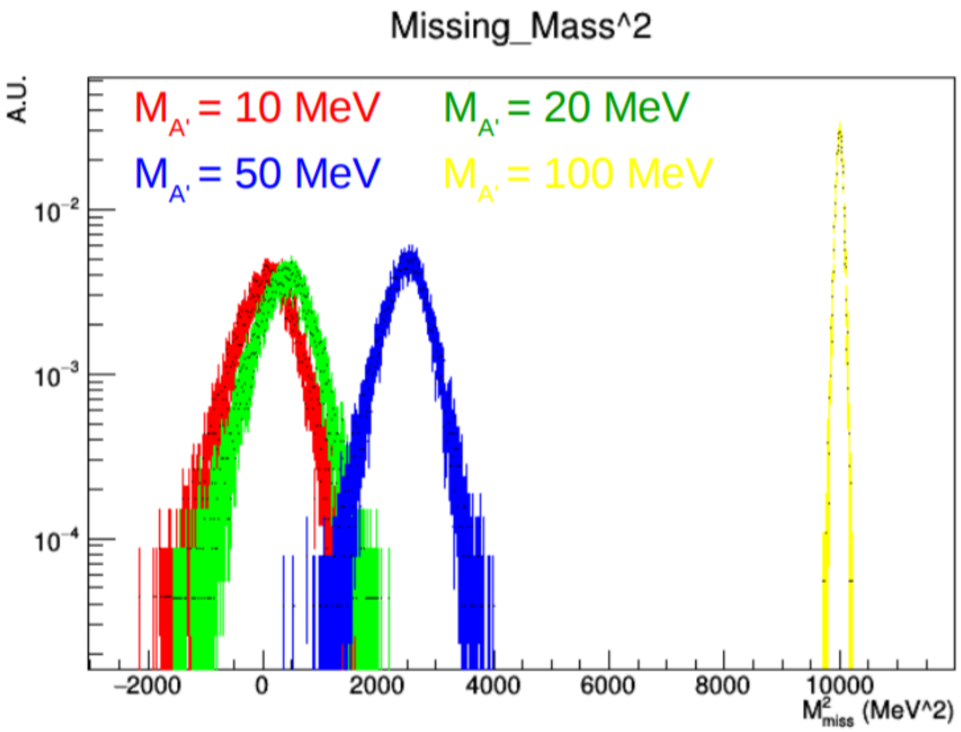
$$M^2_{MISS} = (P_e + P - P_\gamma)^2$$

- Search for a peak over Standard Model background

- Sensitivity of proposed experiments is limited by available energy in CM, going as $\sqrt{E_{BEAM}}$.
- 11 GeV e+ beam@JLab would allow to search for *A'* masses up to 106 MeV

Thin target setup

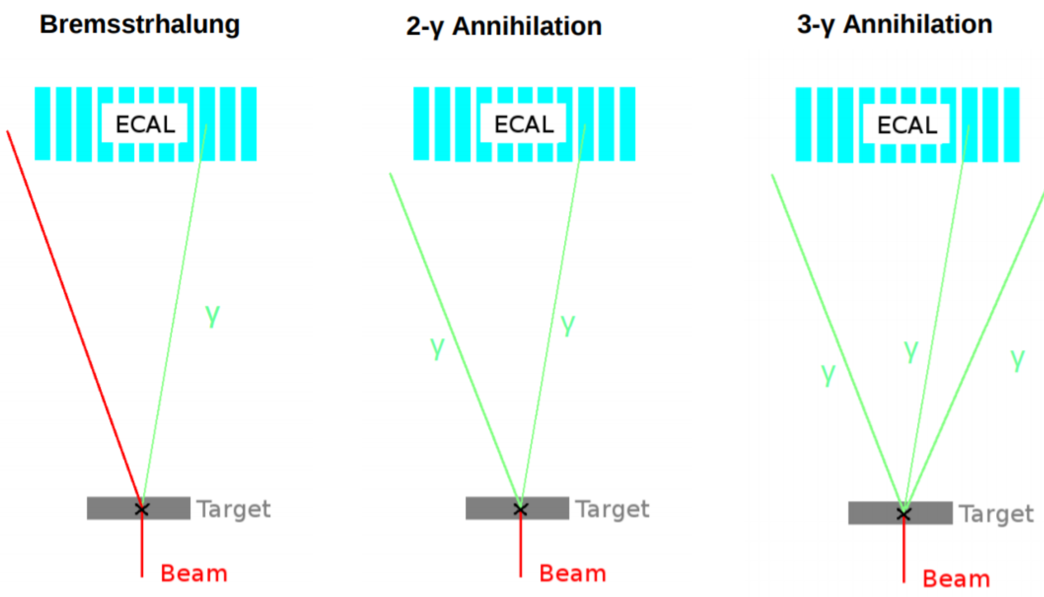


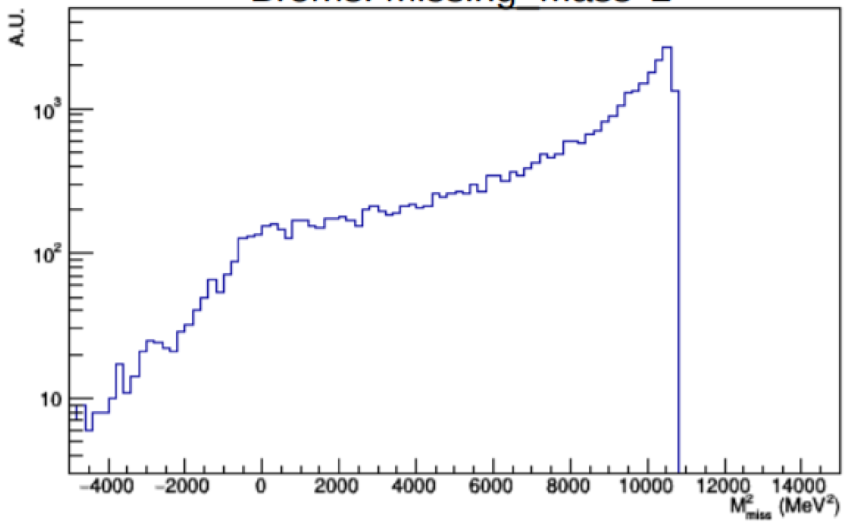


- 100 μm carbon target (good compromise between density and low A/Z ratio)
- Constant magnetic field of ~1 T over a 2 m region downstream the target to bend charged particles
- 50 cm radius **electromagnetic calorimeter** (energy resolution: σ(E)/E = 0.02/sqrt(E))
- Crystal front face 1X1 cm^2 → angular resolution: 0.5 mrad
- **Veto system** (plastic scintillator) to reject from background events (mainly bremsstrahlung)

Expected Backgrounds Evaluation

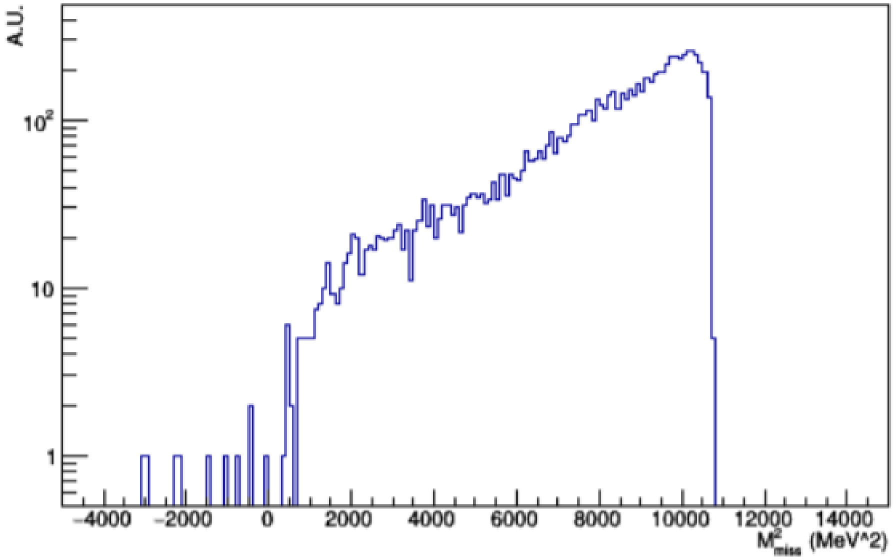
All processes resulting in a single photon in the Ecal contribute to background:





- **Bremsstrahlung** (main bkg. source) rate estimated through GEANT4
- **$e^+ e^-$ annihilation in 2 γ and 3 γ** evaluated using CALCHEP

3-γ missing mass spectrum



- 2-γ annihilation is negligible due to kinematics
- 3-γ annihilation can't be neglected
- Brems. rate limits the max current to ~100 nA

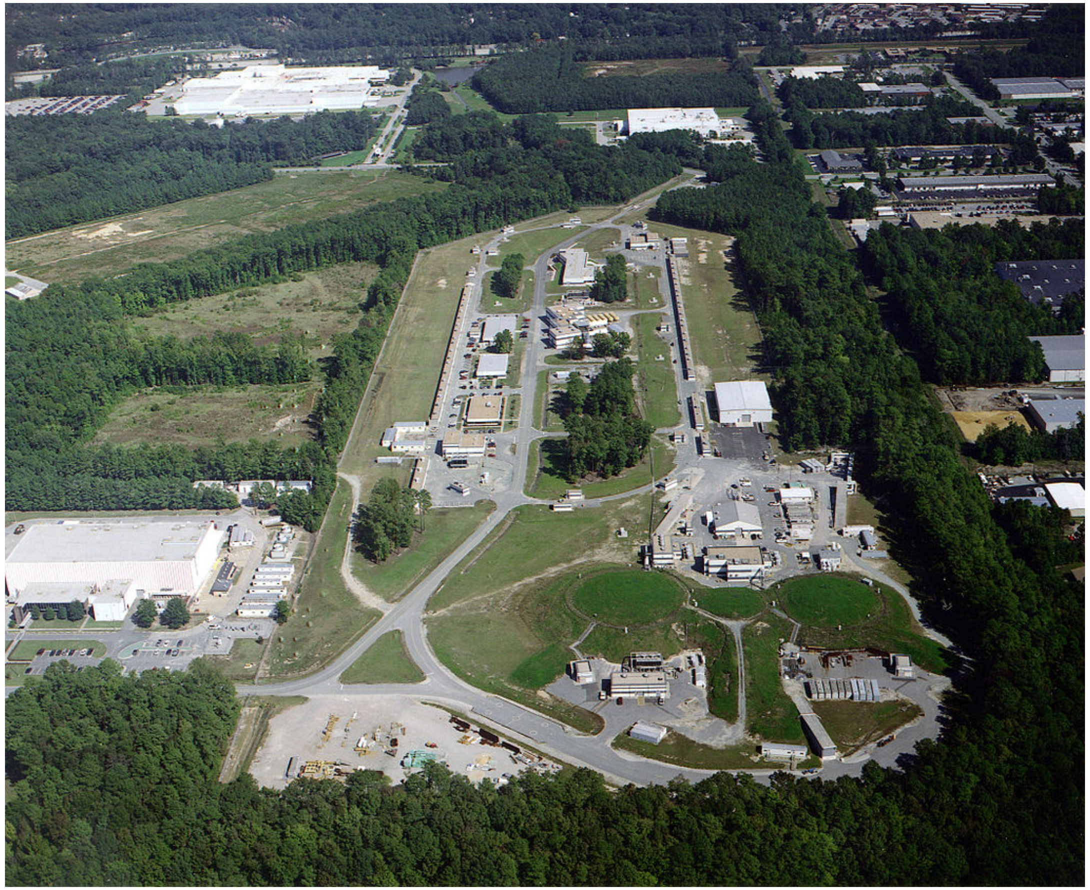
PADME@JLab

Reusable PADME components:

- Target - the PADME carbon target can be easily transferred and installed in the CEBAF accelerator
- Calorimeter - PADME Ecal meets all requirements of the experiment (energy resolution, angular resolution, dimension)
- Veto System - technology and front-end electronics from PADME veto can be reused

New apparatus is necessary:

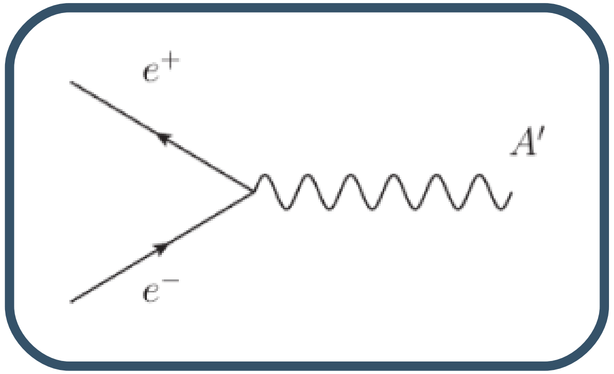
- DAQ system - Not suitable for a continuous structure beam



Required beam parameters

- Current: ~100 nA
- Energy: 11 GeV (max $m_A \sim 100$ MeV)
- Continuous structure
- Momentum dispersion < 1%
- Angular dispersion < 0.1 mrad

Thick Target Setup – Missing Energy



Detector Components:

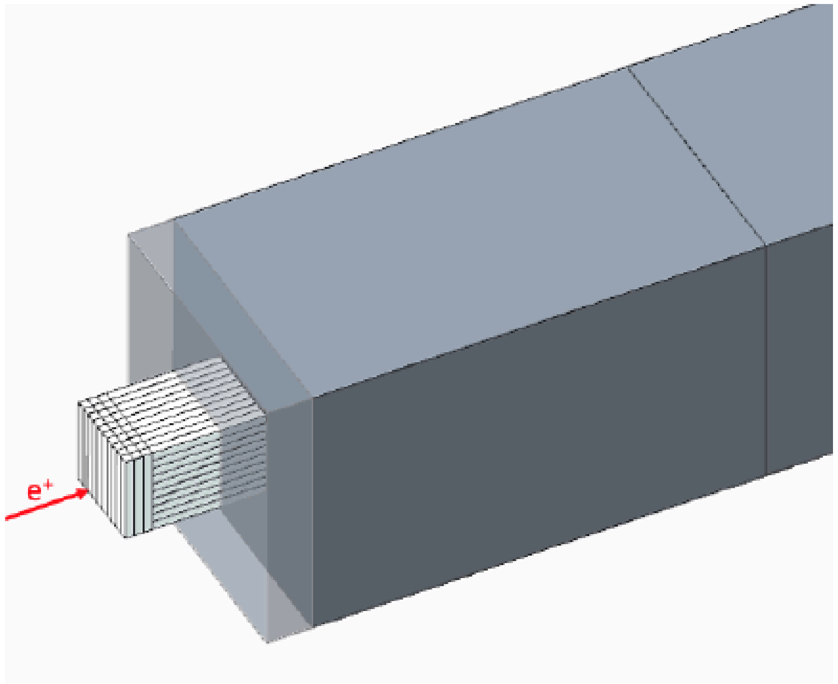
- Electromagnetic calorimeter: 10X10 matrix of 2X2X25 cm^2 $PbWO_4$ crystals (28 X_0 length)
- Hadronic calorimeter: modular iron/scintillator inhomogeneous calorimeter surrounding the ecal to avoid any particle leakage (15 nuclear interaction lengths foreseen)

- Low current 11 GeV positron beam impinging on active target (1 e^+ per ~ 1 μs) → **Non trivial R&D necessary to achieve such beam sructure at Jefferson Lab**.

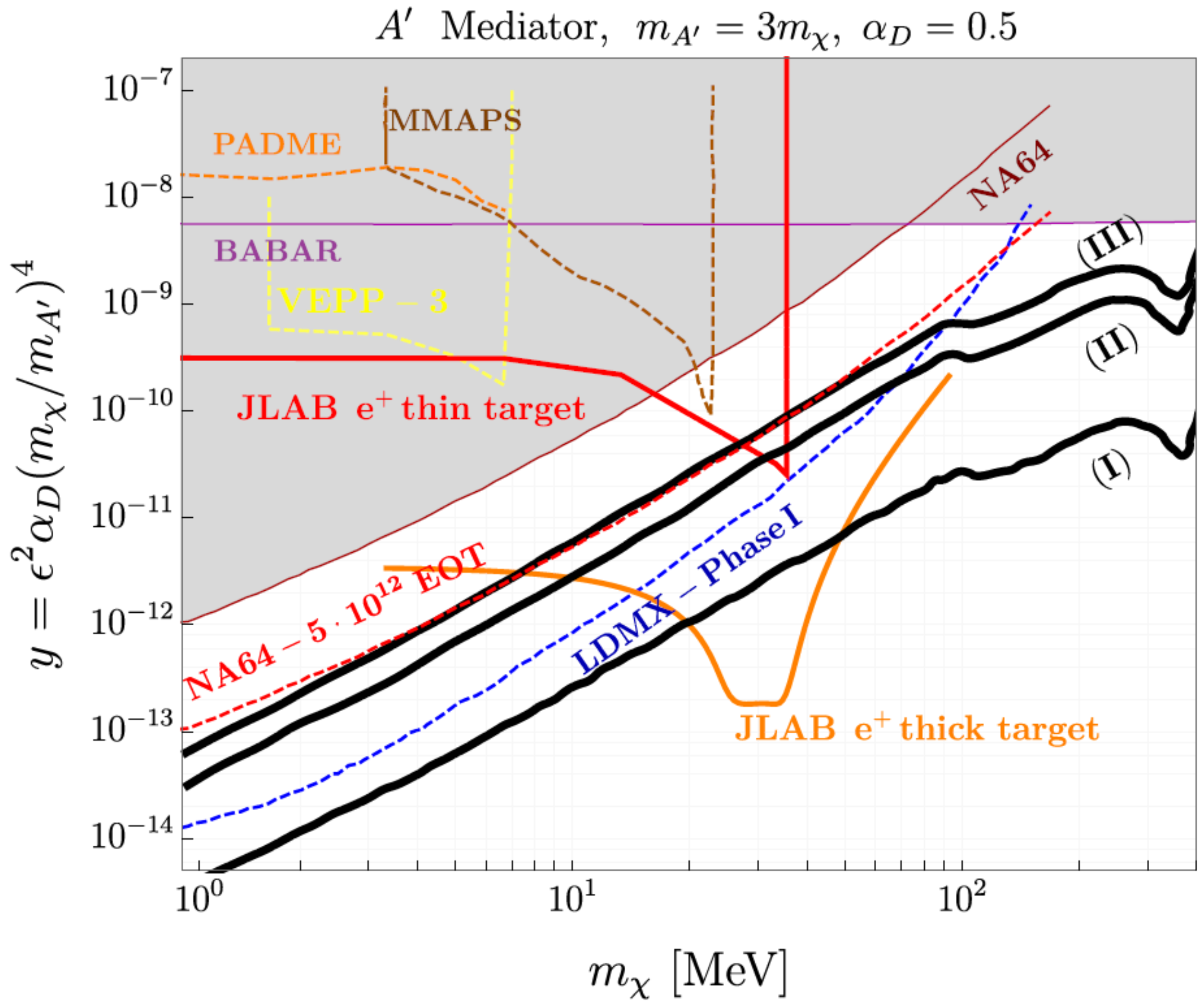
- Primary positron produces an electromagnetic shower in the target (large number of secondary positrons produced)
- A' is produced through resonant annihilation and leaves the detector without interacting
- **Missing energy** is kinematically constrained by the A' mass:

$$m_{A'} = \sqrt{2 m_e E_{miss}}$$

- → Signal signature: peak in the missing energy distribution



Projected sensitivity



Thin Target - PADME@Jlab:

- 185 days measurement run with 100 nA beam current
- Signal and background evaluated through GEANT4 simulations and CALCHEP calculations

Thick Target (Missing Energy):

- 10^{13} positrons on target (order 1 year measurement)
- Signal evaluated through MC simulations
- 0 background events assumed

Conclusions

- A 11 GeV positron beam would allow to search for Dark Photon using different strategies: missing-mass, missing-energy.

- A PADME-like experiment at JLab would benefit from the CEBAF beam characteristics (high current,high energy, continuous structure). The sensibility of the experiment would be constrained mainly by the high bremsstrahlung rate on the Ecal crystals.

- It is possible to reuse part of the existing PADME experimental apparatus as the starting point for the new thin target experiment at the CEBAF accelerator.

- A preliminary study on the feasibility of missing energy experiment exploiting resonant positron annihilation has been conducted. The projected reach of this measurement is very promising. Realizing the positron beam structure necessary is more challenging (dedicated R&D is required) than in the PADME-like setup.

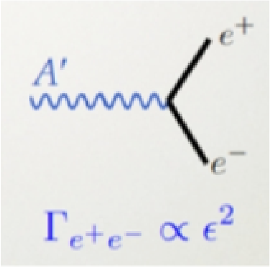
Thanks for the attention!

Dark Photon Signatures

Two possible signatures for **on-shell** dark photon:

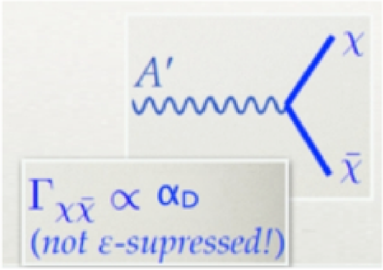
Visible: $A' \to e^+e^-$

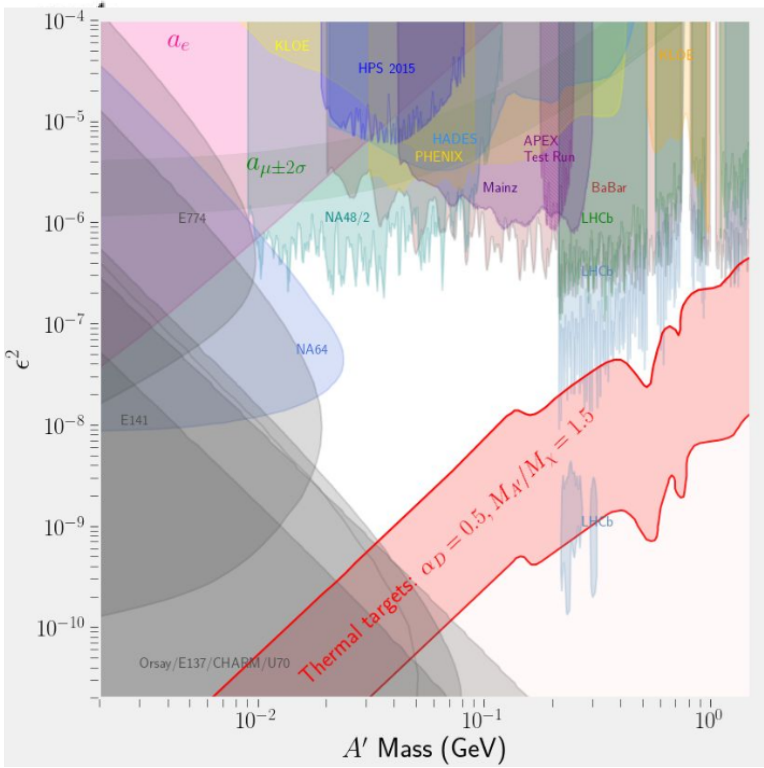
- $m_{A'} < 2m_\chi$
- Decay time depending on ε^2

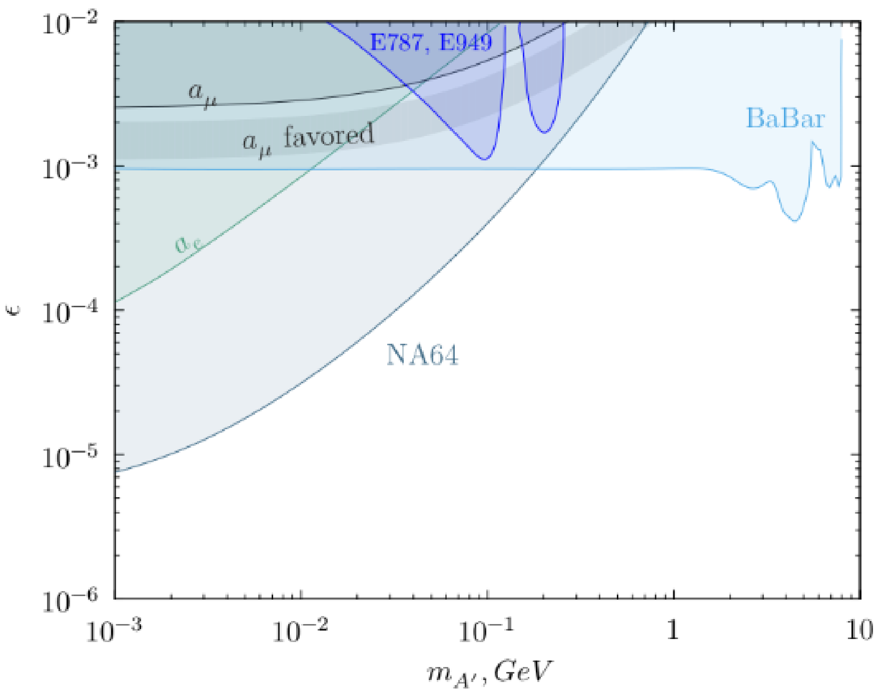


Invisible: $A' \to \chi\chi$

- $m_{A'} > 2m_\chi$
- Not depending on ε







This is the scenario addressed by BDX